

PARSEK: A New Integrated Package for Plasma Simulation Based on Particles

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Plasma physics involves a multiplicity of processes and scales that require a multiplicity of models. We are developing a new tool designed to address such complexity by resorting to a common approach: the use of particle algorithms. The applications of plasma simulation include the new international fusion reactor device ITER [1], laser-plasma interaction, space and astrophysical problems, and industrial applications in the field of material science and processes.

Plasma simulation requires the study of a N-body problem from its most fundamental single particle level, to the kinetic level, and finally to the fluid level. Our aim is to use a single algorithm and software paradigm capable of describing all levels for a given system. We focus our attention to particle algorithms. While other methods might be more popular at some level of description, particle-based methods are commonly and widely in use at all levels of description.

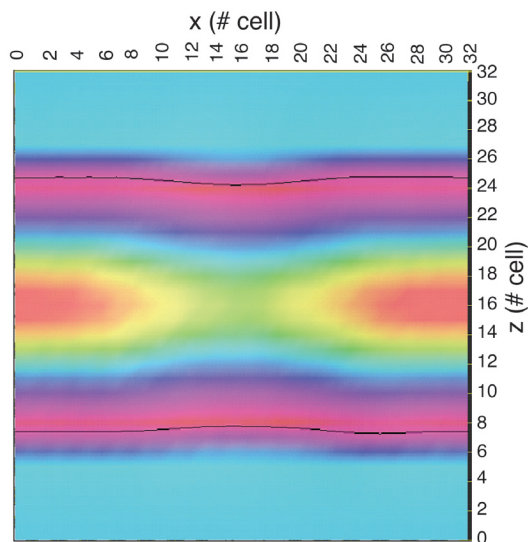
Table 1 reports the crucial features of the different levels of description relevant to the present study. All methods are characterized by four fundamental ingredients: the definition of the particle, of the fields, of the direct interactions (pair interactions or collisions among the particles) and of the interactions mediated by the fields. All methods listed in Table 1 are widely used in the scientific and engineering community and all are available to the proposing team in the form of highly successful and extensively used codes.

Based on this approach we have developed a new software environment, PARSEK [2], that includes modules and tools for particle simulation at all levels described in Table 1. The project is ongoing but a number of published concrete results are already available. The approach is unique in two respects.

First, the methods involved are all available and solidly tested. We are not developing new numerical algorithms but are using previously available tools. Furthermore, the methods used are already available to us from previous computer codes developed at the Laboratory over the years. This is a crucial point, as computer codes are not the simple backbone algorithms published in journals but rather are complex organisms composed of parts whose function might not be immediately recognized. By relying on previous codes we are inheriting a whole expertise and not just method.

Table 1. The different levels of description widely used in the scientific and engineering community.

Method	Particle	Field	Particle-Particle interaction	Particle-Field interaction
Particle-Particle (PP)	Physical particle	NO	collisions	NO
Particle-Particle, Particle-Mesh (P ³ M)	Physical particle	E,B	collisions	Lorentz
Particle-Mesh (PM)	Element of phase space (sample)	E,B	NO	Lorentz
Fluid PIC	Element of fluid	E,B,n,v,T,...	SPH	Lorentz, Drift,...



An added benefit of our approach is the large previous body of verification and validation efforts involved.

Second, the specific tools we use are based on implicit algorithm. In particular, at the kinetic level we use the CELESTE implicit PM moment algorithm [1]. At the fluid level we use the implicit fluid PIC method, FLIP [2]. Both approaches were developed at the Laboratory and are uniquely available here. Such tools are proven in their ability to handle multiple scales in space and time. In the last decade, the two codes have been used extensively and their properties are tested and proven.

An example of the use of PARSEK is shown. Figure 1 shows the formation of a magnetic island in the classic GEM Challenge benchmark [1]. The electromagnetic vector potential is displayed in a false color scale, and the island is shown by the red area (periodic boundary conditions are used). For the same problem Fig. 2 shows the parallel performance.

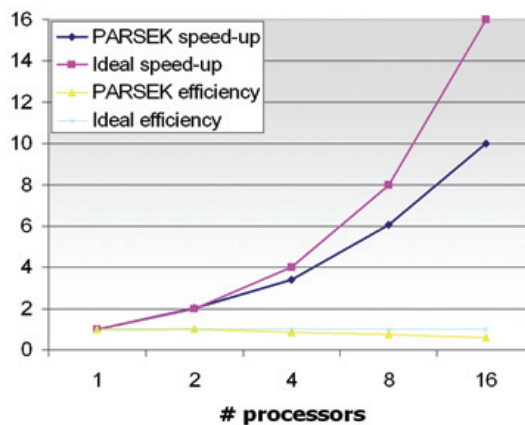


Fig. 1.
GEM Challenge [1]: plot of the electromagnetic vector potential where the formation of a magnetic island in a current sheet is observed as the red area (periodic boundary conditions are used).

Fig. 2.
PARSEK: parallel performance on the T-15 cluster.

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[1] G. Lapenta, et al., "Kinetic Approach to Microscopic-macroscopic Coupling in Space and Laboratory Plasmas," *Phys. Plasmas*, submitted 2005.

[2] G. Lapenta, S. Markidis, *Lecture Notes in Comput. Sci.*, **3516**, 88 (2005).